Agent-based modeling on interaction between water and labor availability in rainfed rice ecosystem, northeast Thailand

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Abstract

An Agent-Based Model (ABM) was co-designed with local rice farmers to represent the human-environment interactions between land/water use and labor management. A rainfed area of Ubon Ratchathani Province, Thailand was the study site. This ABM evolved along a Companion Modeling (ComMod) process to integrate the research team's scientific point of view with the local farmers' desired development outcomes. The model consists of four interacting components: Climate, Hydrology, Household, and Rice. The "Household" is a rule-based agent that makes daily decisions on the different stages of rice production including water and labor availability. Four main rice decision-making processes are modeled: i) nursery establishment, ii) transplanting, iii) harvesting, and iv) post harvest decisions including labor migration. The toposequence of lower to upper paddies and types of land use (water bodies, human settlement, paddy fields) are defined in model's spatial settings. The paper describes the structure of key decision-making algorithms implemented in this ABM. The participatory use of this model to facilitate the discovery and assessment of different water and labor availability scenarios is also explained. The impact of such scenarios on farming practices and labor management is also analyzed and discussed.

Media grab

An agent-based model was designed with farmers to integrate indigenous and academic knowledge leading to a shared representation of interactions between water and labor availability in Northeast Thailand.

Introduction

The Northeast region of Thailand is known as the poorest in the country. Most of its inhabitants are resource-poor workers in the agriculture sector (NSO, 2007). Rice is extensively grown in rainfed areas but productivity is low because of erratic rainfall distribution and coarse-textured infertile soils. To escape from poverty, many Northeast farmers from 20 to 35 years old increasingly out-migrate to search for more profitable employment in the industrial and service sectors. Northeast Thailand has the largest percentage of out-migration - more than a third of all interregional migration originated from this region (Santiphop, 2000). Labor migration is considered an adaptive strategy of these resource-poor farmers to cope with agro-ecological constraints.

Interactions between land and water use; and labor migration as key constraint to farm performance is not yet studied. This research proposes to gain better understanding of these interactions so that a more practical development options can be discovered. By working together, both researchers and farmers provide unique technical and local contributions. We hypothesize that the co-designing of an ABM through the ComMod process (Bousquet and Trébuil, 2005) constructs a shared representation of the agro-ecosystem and farmers' decision-making process that improves analysis and understanding of potentially intricate water, land and labor interactions. The ABM simulation is a tool for the analysis of a complex system, in which human decision-making process is an integral part (Gilbert, 2008). This co-designed ABM is further simulated to explore additional land, water and labor use scenarios with local farmers' participation.

22 farmers in the Ban Mak Mai village located in Det Udom district, Ubon Ratchathani province participated in the modeling process to understand their decision-making processes. The village is a typical rainfed rice producing area of lower Northeast Thailand composed of diverse farming households with different living conditions ranging from very small to large farm holders (Naivinit et al., 2007). In this paper, we start with a description of the ABM "Ban Mak Mai (BMM) model" regarding its spatial, temporal and social settings as well as three key interacting modules followed by the sequence of farm and non-farm activities operating in the model within a crop year. The results regarding the model validation and identification of scenarios proposed by local farmers are discussed.

Description of Ban Mak Mai model

As a product of 3 year long ComMod process, the co-designed and integrative BanMakMai (BMM) model (after the name of the village where we conducted this study in Ubon Ratchathani province) facilitated by researchers is intended for knowledge exchange between researchers and local farmers. The first stage of the BMM model focuses on two main purposes, data acquisition and model validation, in order to improve the model. The second stage emphasizes use of the BMM model for field scenario exploration with local farmers. Concentration is on agro-ecological, economic, and social changes as a consequence of interactions between agents and the virtual rice production area.

Spatio-temporal settings
The BMM model's spatial configuration has a field, farm, and community level representing three land uses, paddy fields, water bodies such as farm ponds and stream, and human settlements like houses, villages, and roads as shown in Figure 1. The smallest spatial unit, or a cell, is equal to 0.16 hectares (1 ngan in Thai unit). Each cell's elevation from 97 to 133 meters represents upper and lower paddies. The sandy Korat soil series typically found in this area (Aumsamut and Boonsomphonphan, 1999) is applied to each cell**.** A paddy field is the aggregation of cells, and a farm is the aggregation of paddy fields. To represent the heterogeneity of farm size and water availability, two small farms (3.3 hectares) and two large farms (6.5 hectares) with different farm pond sizes were created. A simulated year represents one crop year starting on 1st of April. A daily time step is used as local farmers make daily production management decisions. The BMM model is designed to run up to 10 simulated years.

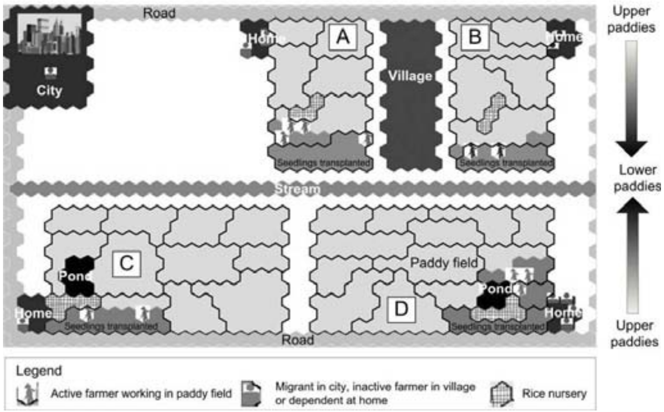

Figure 1. Spatial configuration of the BMM model representing two small farms (A and B) and two large farms (C and D) during transplanting.

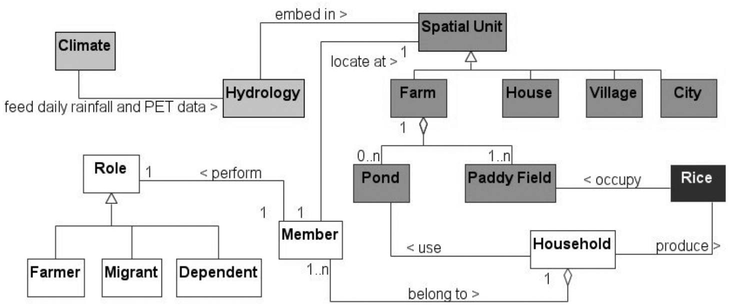

Figure 2. The BMM conceptual model in a UML class diagram representing key entities and their relationship.

Overview of the structure
The BMM model's structure consists of three key interacting modules: Hydroclimatic (hydrology and climate), Crop (rice) and Household (Figure 2). All modules refer to the spatial unit where different land uses are identified.

Hydroclimatic module
This module is embedded in the spatial unit to balance water availability. Four virtual hydrological tanks for ponding, root zone, sub-soil, and water storage are arranged vertically depending on land use type. For instance, a paddy field is composed of a ponding tank on top, a root zone tank in the middle and a sub-soil tank at the bottom while only a water storage tank is in a pond. Two actual parameters, daily rainfall and potential evapotranspiration (PET), are fed into the Hydrology. Data on daily rainfall and PET is from the regional meteorological center located in Ubon Ratchathani province. Ten years of different actual climatic data are used. The hydrological processes depending on daily rainfall patterns previously developed to simulate the availability of water in paddy fields and ponds were integrated in the BMM model (Lacombe and Naivinit, 2005).

Crop (Rice) module
The agronomic characteristics of rice indicate the actual growth stage from seedling to ripening. This module provides information to the Household regarding the rice growth stage at any given time. Information from this module prompts the Household to make corresponding actions relevant to the current rice growth stage. However, the climatic condition (wet or dry) also determines whether such action is possible.

Household module
This module integrates three social levels: individual, household, and village. It has six interacting entities: Household, Member, Role, Farmer, Migrant, and Dependent (Figure 2). A Household is a group of Members whose role can change over time, depending on the activity at a given moment. The Member is in charge of migrating decisions, thus, the location of a Member implies its role. For instance, in a city the Member is in a Migrant role; in a paddy field it is in a Farmer role. Two types of Farmers are identified. One is the Active Farmer working in paddy fields; the other is the Inactive Farmer in the village waiting for employment (Figure 1). To integrate diverse farming households into the BMM model, Households were created with different production means and number of workers. Thus, small farming households A and B have six members but Household A has three labors and three dependents while Household B has four labors and two dependents. Meanwhile, large farming households C and D have two labors and one dependent; and three labors and four dependents, respectively (Figure 1).

Sequence of key activities throughout a crop year
The Household performs a sequence of farming activities. Each activity is driven by interactions between changing climate and rice growth stage, except for the migration decision which is individually controlled by a Member entity. The key activities are as follows: nursery establishment, transplanting, harvesting, post rice harvesting, and labor migration.

Nursery establishment
Water availability provided by the hydroclimatic module is a key trigger of this activity. This depends on the farm pond's water volume or the daily rainfall quantity. Water is pumped by a farmer agent during this period if there are 12 successive dry days to alleviate water stress caused by the dry spell (Table 1). Rice seedlings evolving within the Rice module are ready for transplanting once they are 30 days old.

Transplanting
All Households wait for heavy rainfall before transplanting (Table 1). Once transplanting starts, all members with Seasonal Migrant role need to return home and help the Household produce rice. If a Household cannot completely transplant all rice seedlings on their own in the specified period, additional labor workers are hired (Table 1). Water in farm ponds is not used for this activity.

Table 1. Default values, unit and source of key parameters by module in the BMM model.

Module	Parameter	Default value	Unit	Source
Household	Amount of daily rainfall to start rice nursery establishment	> 20	mm	RPG2
	Amount of daily rainfall to start transplanting	> 20	mm	
	Water quantity need to supply a 0.04 ha nursery	200	m^3	RPG2
	Percent of minimum water level needed to be kept in pond to the depth of pond	10	%	RPG1
	Maximum age for villagers to migrate	45	year old	PS2
	Successive dry day determining the need of pumping water	12	day	
	Average annual household net income	20,000	baht	NSO, 2007
	Average farm input cost excluding labour cost	3750	baht/ha	OAE, 2005
	Amount of paddy needed for self consumption	350	kg/person/year	Farm survey, 2004
	Price of high quality paddy	18	baht/kg	Thai Rice Mills Association, 2008
	Price of fair quality paddy	12	baht/kg	
	Price of poor quality paddy	9	baht/kg	
	Wage offer during transplanting period	120	baht/person/day	PS2
	Wage offer during harvesting period	150	baht/person/day	
Hydroclimatic	Wet day	20 to 30	mm/day	PS1
	Dry day	10 to 20	mm/day	
	Very dry day	< 10	mm/day	
Crop (Rice)	Maximum paddy yield	2250	kg/ha	RPG1
	Minimum paddy yield	937.5	kg/ha	
	Duration needed for rice seedlings to be mature	30	day	PS1
	Duration needed to complete transplanting	21	day	
	Limited date for nursery establishment	115 (3rd week of July)	day	
	Limited date for transplanting	168 (2nd week of September)	day	
	Limit of harvesting period to get high quality paddy	10	day	
	Date to harvest early maturing rice	224 (10th November)	day	Bureau of Rice Research and Development, 1999
	Date to harvest late maturing rice	235 (21st November)	day	

Notes: *RPG1: Role-Playing Game Session on 9-10 July 2005*
RPG2: Role-Playing Game Session on 10-11 October 2006
PS1: Participatory Simulation on 5-6 February 2008
PS2: Participatory Simulation on19-20 March 2008

Harvesting
Two harvesting dates are used, depending on the rice variety (Table 1). Households are triggered to harvest once the defined harvesting date defined in the Rice module arrives. A number of laborers are critical to this activity because fast harvesting time yields higher quality paddy. This paddy can be sold at a high price in the market (Table 1). The concept of this algorithm is that all farms are to:

- Get high quality paddy before December 1, or
- Get fair quality paddy until December 9.
- After December 10, additional laborers are no longer needed because the designated harvesting deadline has passed.

Post harvesting and labor migration
Once rice production activities are finished, Households compute the net income. Sources of income are from selling rice, earned wages, and remittances. Expenses are in the form of farm inputs including labor cost and other household expenses. Afterwards, the demographic characteristics of Member entities are updated. The criteria to become a potential Migrant is based on the combination of two factors – the Member's demographic

characteristics; and the social and economic status of its Household (De Jong, 1997). Meanwhile, two kinds of migration are taken into account. The Seasonal Migrant who always returns home to help in rice production is considered a family laborer, while the More-permanent Migrant is removed in the list of family laborers. At the end of the activity, Members can decide to move to the city or stay in the village.

Results and discussion

Use of the BMM model has two steps. Scenarios are first identified and then local farmers are tapped to analyze these proposed scenarios. In the end, participating local farmers discussed two scenarios on water and labor availability during a participatory simulation workshop. The participants are aware of the consequences of interactions in different scenarios. For the unlimited water availability scenario where all farms have farm ponds full of water, the synchronization of rice farming activities (all farms are able to start producing rice at the same time) induced problems for larger farms due to lack of available hired labor. Furthermore, there is a higher risk of rice production failure as well as higher farm input costs as agents start nursery establishment sooner to take advantage of the available water. One virtual farm did not complete the transplanting activity because the heavy rains came late, and by then some rice seedlings were too old to be used. For the unlimited labor availability scenario, small holder households A and B lost some income from wage that they received from household C and D in the limited labor availability scenario. In the scenario without labor shortage, large farming households C and D earned more despite labor costs because they yielded high quality paddy that can be sold at a higher price. However, thorough analysis is needed to better assess the agro-ecological, economic, and social impact of the interactions between different levels of water and labor availability.

Conclusion and perspective

Based on the monitoring and evaluation activity carried out with participating farmers, the BMM model sufficiently represents the interactions between water and labor availability of their community. As a consequence of the collaborative modeling process, researchers and local farmers both gained better understanding of these interactions through the simulation analysis of changes regarding farming practices, and migration behaviors of agents. The BMM model is gradually developed based on this common understanding. As an integrated knowledge tool, the BMM model is used in a series of participatory simulation workshops. This model will further be used to analyze and assess scenarios regarding water and labor availability, and bring it back to the field for collective discussion and knowledge-sharing among local famers.

Acknowledgements

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